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THESIS

A STUDY OF THE EFFECT OF PROCESSING VARIABLES ON THE MECHANICAL PROPERTIES OF 5 INCH CARTRIDGE CASES

by

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October 1982

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In summary, it is found that stress relieving the roll-straightened specimens produces strain aging which results in an increased yield strength and a restoration of a distinct yield point. The Navy method will better represent the actual yield strength of the case if the stress relief treatment is omitted as no increase in yield strength was measured due to various straightening techniques.

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A Study of the Effect of Processing Variables on the Mechanical Properties of 5 inch Cartridge Cases

by

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ABSTRACT

The yield strength of 5 inch cartridge cases (1030 steel) has been previously shown to be dependent upon the preparation method used for the test samples. The samples prepared by a procedure used by the Navy were roll-strengthened and stress relieved and the samples prepared by an Army method were straightened and not stress relieved. The samples prepared by the Navy test method gave a relatively high yield strength compared to samples prepared by the Army method.

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I. INTRODUCTION

The present modern deep-drawn steel cartridge case requires specific mechanical properties. These properties must be such that the steel will expand in the gun chamber and obturate satisfactorily during firing but must be resilient enough to allow easy recovery or extraction after firing.

These required mechanical properties (i.e., strength, expansion, and contraction capabilities) are developed and controlled by judicious use of heat treating and metal forming procedures.

The expansion and partial contraction is directly related to the elastic and plastic characteristics of the material. These two characteristics are a direct function of the yield strength of the material and thus, the yield strength should indicate the performance capabilities of a case.

In order to establish a standard method of yield strength measurement, it was suggested that different facilities should be involved in an extensive testing program. These facilities were Seal Beach, Norris Industries, Frankford, and Indian Head. These facilities performed tensile tests on samples prepared by both the Army

and Navy method [Ref. 1]. Some of the conclusions that they obtained after several different kinds of tests are:

1) The method of specimen preparation had a definite effect on yield strength values both in average and data dispersion. Hand straightening the test specimens (Army method of preparation) resulted in low mean values with large data dispersion. Mechanical roll-straightening followed by stress relieving (Navy method of preparation) resulted in higher mean values with less data dispersion.

2) Analysis of test results of the test gage area which included the looper pattern (grain orientation produced by rolling and extended by drawing), disclosed no correlation between grain orientation and yield strength values. Yield strength values were distributed normally and thus could be used for statistical evaluation of the quality of a part. Ultimate tensile strengths were also normally distributed but slightly skewed and should not be considered in the statistical evaluations.

3) Elongation and hardness values were not of a normal distribution and were considered invalid for statistical evaluation of the quality of a part. Elongation and hardness values are only useful in indicating material anomalies and should be retained for that purpose only.

4) The size of test specimen had no noticeable effect on the test data.

5) Mechanical properties do not differ significantly from cartridge case to cartridge case.

6) Improperly prepared specimens resulted in test specimens incapable of producing valid reliable data.

7) The Navy method of specimen preparation must be used if the 135 Kpsi and 90 Kpsi minimum yield strength requirements for the case base area and side wall area are specified.

8) Maintain elongation, ultimate strength and hardness as test data but delete them as acceptance criteria.

9) Use statistical analysis of yield strength data as acceptance criteria.

This thesis presents the effect of the various steps of the sample preparation method on yield strength (straightening and stress relief).

II. BACKGROUND INFORMATION

A. MANUFACTURING PROCESS FOR A 5 INCH CARTRIDGE CASE

Ordinarily iron may have a tensile strength of 40 Kpsi, but the introduction of fractional percentage points of alloying elements such as carbon followed by heat treatment can produce as much as tenfold increase in strength. Different heat treatments can produce different combinations of strength and ductility within these limits.

Maximum strength is obtained by the heat treatments that involve three distinct operations: 1) Heating the steel to a relatively high temperature so as to convert it to austenite; 2) Quenching (rapid cooling) of the hot steel to form martensite and 3) Tempering the martensitic steel by heating to a relatively low temperature so as to obtain the desired reduction in hardness and increase of ductility. The proper combination of strength and ductility is critical to the usefulness of the engineering alloys. In the heat treated medium carbon steels, the balance of strength and ductility can be closely controlled and is one of the most satisfactory to be found in engineering alloys.

Steel used for most cartridge cases conforms to MIL-S-3289 (AISI-C1030) which establishes a carbon content range of 0.25% to 0.35%. Carbon on the low side of this

range reduces the hardness and strength that can be developed, whereas a carbon content that approaches or exceeds 0.35% may cause reduced ductility.

Cartridge case steel is aluminum-killed because it is desirable that it be fine grained and have nonaging characteristics. The material also must be spheroidized for greater formability. A hot-rolled pearlitic structure may cause excessive fracturing of the metal, especially during the initial drawing operation. Complete spheroidization is not necessary but it should progress to the point where the pearlitic structure is broken up.

The base stock for a steel case may be procured from the mill in the form of a blank or a disk of the specified gage and diameter or in plate form to be blanked by the case manufacturer. Each blank must be inspected on both sides for defects which could cause failures during manufacture.

Manufacturing operations in the production of a steel cartridge case proceeds from the blank and precup through successive drawing, forming and machining to the finished case. The number of draws employed to form specific case depends upon the amount of reduction in wall thickness. The part must sustain from the cupping operation to the final draw. Each drawing operation work-hardens the steel to the extent that it is necessary to anneal, pickle, and lubricate the part before further cold-working can be performed.

The first drawing operation which forms the initial head section of the case and the first few inches of the side wall is the cup. To prevent fracturing of the metal because of subsurface defects in the metal, the cupping operation is divided into two parts, precup and final cupping operation.

The forming of the head section is critical because of the notch sensitivity of steel. There must be no evidence of stress raisers in the internal radius section of the case which joins the head and the side wall. To prevent the formation of any stress raisers, the head is formed in two separate operations; prehead and finalhead. This procedure provides the measure of control over the grain flow of the metal required to prevent the formation of any stress raisers. The prehead operation distributes the metal in the head section so as to facilitate the formation of the primer boss and the extractor flange during final heading. Because of the notch sensitivity of the work-hardened structure, the cases are annealed between preheading, and final heading. This annealing provides a more ductile structure and thus greatly reduces notch sensitivity.

The cartridge case expands during the actual gun firing and contracts after firing. The comparatively thin side wall results in an expansion that is both elastic and plastic. To extract readily from the gun after firing, the case must recover elastically to dimensions equal to or less

than the gun chamber. The amount of elastic recovery depends upon firing pressure and the yield strength of the case. The yield strength is governed by the heat treatment and the subsequent tempering of the metal structure to the desired mechanical properties.

During manufacture, the cases are austenitized and quenched to give the correct mechanical property values for tensile, hardness, elongation, etc. The cases are fully austenitized at 1620F (+10, -20) and quenched in brine at 65F (+5, -5). Final heat treatment consists of taper annealing at 1120F (+20, -20) for a maximum time of 7 minutes. However, the taper anneal applies only to a portion of the case approximately 10.5 inches from the base to the case mouth. This taper annealing procedure produces areas with different hardness and strength values and a transition zone between two. The final contour of the body section of the case is formed during a mechanical tapering operation that follows the taper anneal. Finally the entire case is stress relieved at 710F after tapering.

The face of the head, extractor flange and primer hole are then machined to the finished dimensions. The side wall is then trimmed to length and the mouth edge is chambered. Cases with threaded primer holes are then tapped. To facilitate crimping of the case to a projectile or a closure plug, the mouth area of the case is then annealed. This

mouth anneal helps prevent cracking during the crimping operation, and splits in the mouth during firing.

The final operation in the manufacture of a steel cartridge case for the Navy is to provide a protective coating of zinc plating to prevent the formation of rust or other corrosive products.

The cases are processed in an elevator-conveyor type of machine that is fully automatic. The process includes a chemical cleaning operation, a zinc plating operation and a final chromate conversion coating on the zinc plate.

B. ELASTIC AND PLASTIC PROPERTIES

The elastic constants of a crystal are essentially a measure of the force required to displace the atoms of the crystal relative to one another and so are directly related to the binding forces between the atoms.

Because the elastic constants are so closely related to the interatomic forces, very little can be done to alter them in any given material. They can be changed moderate amounts by alloying but are relatively insensitive to cold work, or any other treatments that can be applied to a material.

A polycrystalline metal where the grains are at random orientation with respect to each other behaves as it were an isotropic elastic material with elastic constants which are averages of those of the individual grains.

The plastic properties of crystals are structure sensitive, i.e., dependent on the imperfections present in a particular sample of material as well as the characteristics of the perfect crystal.

C. YIELD STRENGTH

When a material under tension reaches the limit of its elastic strain and begins to flow plastically, it is said to have yielded. The yield strength is then the stress at which plastic flow starts. In most cases there is a gradual transformation from elastic to plastic behavior. In fact if one works with sufficiently sensitive techniques he can find evidence of permanent deformation in the material even in the early part of the elastic region.

It is clear then that the yield strength is at best an arbitrarily defined point on the stress strain curve. The most commonly used method of defining the yield point is to construct a parallel line to the elastic part of the stress-strain curve but displaced to the right an amount equivalent to a plastic strain of 0.20%. The stress at which this line intersects the stress-strain curve is the 0.20% offset yield strength [Ref. 2].

D. PRECIPITATION HARDENING

When an alloy is heated to a single phase region of its equilibrium phase diagram and then cooled to a temperature

corresponding to a two phase region of the phase diagram, the alloy will be supersaturated with solute which will begin to precipitate out of solution. The precipitating phase will in general have a different crystal structure and specific volume from that of the parent phase. Formation of precipitate particles within a homogenous solid solution will result in severe local distortion of the matrix, creating concentrations of elastic-strain energy in the vicinity of the precipitating particles. This elastic energy plays an important role in determining the form of the precipitate particles.

Precipitating in age-hardening alloys begins with the formation and growth of fine solute rich clusters or GP zones that form in the matrix. GP zones form and coarsen early in the aging process.

Iron-Carbon alloys are not easy to study but several interesting studies of aging of quenched austenite have been made. So far no GP zones have been detected on aging. The first precipitates are platelets of a transition phase which is probably the E-Carbide found in martensite formed when medium carbon (ex. 1030 steel) austenite is transformed to martensite. E-Carbide is the HCP transition phase which is coherent along the 100 planes of the alpha iron. The fine E-Carbide precipitate hardens the steel appreciably, though the net increase in strength on transferring carbon from the

clusters and dislocations to the precipitates are small. Heating to a higher temperature or holding for longer times leads to the formation of fine semicoherent platelets of Fe_3C. Since this phase is thermodynamically more stable than the coherent E-Carbide, it drains carbon from the matrix and from the E-Carbide, leading to the slow elimination of the E-Carbide and replacement with a coarser, but still fine, semicoherent Fe_3C (cementite). This growth of cementite at the expense of the E-platelets leads to much of the softening [Refs. 3, 4].

E. X-RAY DIFFRACTION

Of the many kinds of crystal imperfections, the ones we are concerned with here are those which create non-uniform straining. Non-uniform strain in the lattice is characteristic of the cold worked state of metals and alloys. When a polycrystalline piece of metal is plastically deformed, (ex. by rolling) slip occurs in each grain and the grain changes its shape becoming flattened and elongated in the direction of rolling. The change in shape of any one grain is determined not only by the forces applied to the piece as a whole but also by the fact that each grain retains contact on its boundary surface with all its neighbors. Because of this interaction between grains, a single grain in a polycrystalline mass is not free to deform in the same way as in isolated single crystal would if subjected to the same

deformation by rolling. As a result of this restraint by its neighbors, a plastically deformed grain in a solid aggregate usually has regions of its lattice left in an elastically bent or twisted condition or, more rarely in a state of uniform tension or compression. The metal is then said to contain residual stress. The term 'residual stress' emphasizes the fact that the stress remains after all external forces are removed [Refs. 5, 6]. The effect of strain, both uniform and non-uniform on the X-ray diffraction peaks is illustrated in Figure 1.

When an annealed metal or alloy is cold worked its diffraction lines become broader. As the amount of cold work is increased, the broadening increases. With the processes of recovery, recrystallization and grain growth, the lines get sharpener. So the degree of cold work can be detected by X-ray line broadening techniques, Figure 2.

III. EXPERIMENTAL PROCEDURES

A. MATERIAL DESCRIPTION

Testing was conducted on specimens prepared by the Naval Weapons Station (Seal Beach) and specimens prepared by the Naval Postgraduate School (Monterey).

All specimens prepared by N.W.S. were transverse specimens from circumferential rings cut from preselected areas of the cartridge case according to Figure 3. Half of the rings were straightened and machined as tensile test specimens. The other half of the rings were still semi-circular when supplied to N.P.S.

At N.P.S. three whole cases were used. Test specimens were cut as shown in Figure 4.

Steel used for the cartridge cases conforms to MIL-S-3289 (AISI-C1030) which establishes a carbon content range of 0.25% to 0.35%. Cartridge case steel is aluminum killed and spheroidized for greater formability. Manufacturing of a case includes several steps as discussed in the background information.

B. X-RAY DIFFRACTION LINE BROADENING STUDIES

It is reported in the literature that X-ray line broadening due to non-uniform lattice strain is proportional to the square root of dislocation density [Ref. 6]. From

this it was concluded that X-ray line broadening should be a very useful parameter in quantifying the degree of cold work with respect to resulting dislocation density. X-Ray line broadening has been used to study the degree of non-uniform strain and the effect of cold work.

PHILIPS XRG 3100 X-RAY GENERATOR, PHILIPS NORELCO SCANNER, AND PHILIPS NORELCO DATA-PROCESSOR and CONTROLLER were used. The samples measuring approximately 1/2" x 1/2" were irradiated with Cu radiation and Monochromactic Graphite filter. Twenty degrees of scanning was performed for the (110) peak of Fe for each sample. The peak widths at half maximum (HPW) intensity were measured and recorded. The samples were chosen from the base region of the cartridge case (A-region).

Three different procedures were employed to determine the effects of straightening and stress relieving.

1. Procedure 1

One sample from the circular (unstraightened) ring and one sample from the straightened ring (same ring cut from the case were taken from the base region.

1) The half peak widths (HPW) were recorded without any treatment.

2) They were electropolished with a solution containing 1-part Perchloric acid, 10-parts Glycol-Acetic acid for 30 seconds at 40 VDC to remove any existence of surface cold work. The HPW's were recorded.

3) Then they were subjected to a 610F stress relief for 1 hour and HPW's were recorded to see the effect of stress relieving.

4) Then they were electropolished again (30 sec) and again the HPW's were recorded.

X-ray line broadening techniques can measure the amount of cold work but only very near the surface. Electropolishing can affect the line broadening if surface cold work exists. Electropolishing as described removes approximately 0.0002 inches of material from the surface.

2. Procedure 2

One sample from the circular (unstraightened) ring was taken.

1) Without any treatment the HPW was recorded.

2) Heat treat the unstraightened ring.

1620F (+10. -20) 30 min austenization.

Quenching (65F +5, -5) in water.

Tempering at 710F for 30 min.

HPW was recorded.

3) After heat treatment the sample was electropolished and the HPW recorded.

3. Procedure 3

An unstraightened half circular ring was taken from the base region. To measure the effect of cold rolling during straightening, the following procedures have been employed:

1) Without any treatment a cut from a circular ring was taken and the HPW was recorded, then electropolished and again HPW was recorded.

2) The original half ring was cold straightened. A cut was taken and HPW was recorded, then electropolished and again HPW was recorded. Then 610F stress relief was subjected to the sample and after electropolishing it the HPW was recorded.

3) The straightened original half ring was bent back to a semicircle again by hand and then straightened by the roller a second time. Then cut was taken and the same procedures as (2) were employed.

4) The restraightened half ring was bent to a semicircle again by hand and then straightened by the roller a third time. Same procedures were employed as (2) after.

C. TENSILE TEST PROGRAM

Tensile test program was divided into three groups each having subgroups selected to help understand and detect the effect of straightening, stress relieving, etc. An INSTRON tensile test apparatus was used for that purpose and the 0.2% offset method was used to find the yield stress. An extensiometer was not used; 0.2% offset was measured from the load-deflection curve. Two inches per minute chart speed and 0.05 inches per minute head separation speed are used.

1. <u>Effect of Straightening on Yield Strength</u>

In this part the aims were to determine the actual yield stress of the case (without straightening and stress relief) to detect any anisotrophy and the effects of straightening and specimen preparation.

Three cartridge cases were taken and cut according to Figure 4.

a) Standard circumferential (e,f,g,h, Figure 4) half rings were cut, then they were straightened by the roller and then machined to the desired shape. Finally the test specimens were prepared according to ASTM 8 methods (Figure 5). Then the 610F stress relief was employed and the tensile tests performed.

b) Longitudinal specimens were prepared in the same way, but didn't require straightening by the roller. Thus stress relieving was not required. The aim was to measure the unaltered yield strength in the longitudinal test orientation.

c) In this group a new method was used for the tensile test. Two full rings (a,b, Figure 4) from each of the three cases. Figure 6 shows the design of the specimens.

In this experiment the load is divided into the sum of two reduced sections. The full rings were cut from the head regions as shown in Figure 4. Then they were machined

to the desired width and then the gage sections were machined according to ASTM 8.

2. Effect of Straightening, Stress Relieving and Heat Treatment

Several half rings were sent from Naval Weapons Station (Seal Beach). The half rings were from various locations within several cases and the rings were prepared as tensile specimens by the Navy method at Seal Beach. The other half of the rings were not straightened. In this part five different kinds of tests were employed.

a) The straightened and reduced specimens from the Naval Weapons Station were exposed to 30 min. 610F stress relief. The tensile tests were then completed.

b) The unstraightened half of each ring was roller straightened and heat treated as follows: AUSTENITIZATION (1620F) + QUENCHING (65F) + TEMPERING (710F). The aim was to measure the actual yield stress of the case without any residual cold work.

c) To see the effect of stress relief and the stress relief temperature, tensile tests were conducted on circular rings after straightening with: 1) No stress relief, 2) 400F stress relief, and 3) 800F stress relief.

D. EFFECT OF STRESS RELIEF TEMPERATURE

In this part six rings were cut from the remaining head section of each of the three cartridge cases.

a) Half of each ring was straightened and stress relieved at 610F (30 min.). The other half of each ring was straightened only. Then the tensile tests were conducted.

b) After straightening, half of each ring was stress relieved at 650F (30 min.) and the other half of each ring was stress relieved at 700F. The aim was to see the effect of the temperature of stress relieving on the yield stress.

E. METALLOGRAPHY

Metallographic samples from each region (A,B,C,G,K,J, D,E, Figure 3) were examined. The samples were from unstraightened half rings. The polished specimens were then etched with a 2% nital solution for 3-5 seconds and examined using a ZEISS optical microscope.

IV. RESULTS AND DISCUSSION

In the previous studies discussed in the introduction, the preparation of the specimens had a definite effect on yield strength. Hand straightening of test specimens (Army Method) resulted in low mean values, mechanical straightening followed by stress relieving (Navy Method) resulted in high mean values.

A. X-RAY DIFFRACTION

As stated earlier, when an annealed metal or alloy is cold worked its diffraction lines become broader. As the amount of cold work is increased, the broadening increases. With the processes of recovery, recrystallization and grain growth, the lines get sharpener. X-ray line broadening can measure cold work but only very near the surface. So electropolishing the specimens can show the difference between the surface and inside of material or the surface cold work.

Table 1 shows that both the half peak widths (HPW) of the circular (unstraightened), and straightened samples are the same. This indicates that any changes in the level of the cold work due to straightening is undetectable by this method. Electropolishing and stress relieving both cause a decrease in the amount of broadening, or cold work coming

from the manufacturing. The reduction of the HPW following electropolishing shows that some cold work is concentrated on the surface.

Table 2 illustrates that the HPW is dramatically decreased (much more so than just electropolishing) with the complete re-heat treatment. The electropolishing effect after heat treatment is small but exists. Possible cause is the residual stress due to quenching.

Table 3 shows the effect of extensive straightening with another sample. Although straightened and rebent three times, the straightening effect is still very small. Tables 4, 5, and 6 show the electropolishing and stress relieving effects after each straightening and rebending operation to the same sample. There is considerable difference after the electropolishing confirming the existence of surface cold work.

It seems that the effect of stress relieving on HPW is increasing with the amount of cold work or with the number of straightening operation but if we look at Table 7 it can be seen that this effect is probably coming from the removal of material during each electropolishing step, again illustrating the gradient of cold work that exists through the thickness of the wall of the case.

In summary, the X-ray diffraction tests have shown:

a) The plastic deformation resulting from the straightening procedure was not detectable by means of X-ray diffraction.

b) The cartridge case manufacturing procedure results in a high degree of retained cold work in the case with larger amounts of cold work in the surface regions.

B. TENSILE TESTS

Tensile test programs were conducted on samples with various processing history. The individual results are collected in Tables 8-17 and averaged for comparison in Tables 18-20.

The following were observed using the full ring, standard circumferential and the longitudinal specimens:

a) There is anisotropy in the properties of the cases. Both the tensile strength and yield strength are higher in the longitudinal specimens (Table 18). This is the direction of extrusion of the cases during the manufacturing.

b) The straightened circumferential specimens have a slightly higher strength than the full ring specimens, however determination of the yield stress for the full ring samples was very difficult and these results are thus questionable.

c) Full ring test may provide a good estimate of the actual case yield strength, but considerable developments

are required in the test methods. The non-linear behavior of the samples during loading and the distribution of load to each side of the ring were problem areas for these tests.

Table 19 shows the effect of stress relieving at different temperatures with the samples from different locations of base region. The observations are:

a) Stress relieving gives a strain aging maximum near 400F, but at 600F the yield stress is still higher than the original as-straightened value.

b) With the full re-heat treatment the samples have a much lower strength than expected illustrating that a large amount of strengthening must be imparted during the tapering operation (residual cold work).

c) The specimens obtained from N.W.S. (Seal Beach) have both higher yield stress and tensile stress values comparing to the three cases obtained by N.P.S. This was true whether the samples were straightened by N.P.S. or N.W.S.

Table 20 averages the data from Tables 16 and 17 showing the effect of 610F and 650F and 700F stress relieving treatments.

It is observed that carbide precipitation plays an important role. The tensile strength seem to remain constant but there is considerable increase in the yield following the 610F stress relief. And, the stress-strain curves showed a sharp yield point with the stress relief at

600F, 650F, and 700F, but there was an elimination of sharp yield point when the test was performed without any stress relief (Figure 7). This is caused by strain aging of the straightened sample.

Two specimens from the same ring were tensile tested after a 610F stress relief. One was tested immediately, the other was tested after severely bending it repeatedly. The result was again the elimination of the sharp yield point, and lower yield stress for the deformed sample. The UTS was unaffected by this bending process.

C. METALLOGRAPHY

Samples for metallographic examination from various regions from the head to the mouth of one case were examined. The microstructure of each location is shown in Figure 8.

The microstructure changes from very lightly tempered martensite near the head to over-tempered martensite (ferrite + Fe_3C) near the mouth.

These microstructures are consistent with the change in strength that exists along the length of the case.

V. CONCLUSIONS

1) The plastic deformation resulting from straightening procedure was undetectable by means of X-ray diffraction.

2) The cartridge case manufacturing procedure results in a high degree of retained cold work in the case that contributes to the yield strength of the case. Some of this cold work is concentrated on the surface of the case.

3) There is a slight decrease in residual stress (cold work) with the 610F stress relief, as revealed by the X-ray diffraction, but at this temperature strain aging occurs increasing the yield strength considerably without affecting the tensile strength and restores a distinct yield point.

4) The actual circumferential yield strength of the cartridge case is believed to be about 150 Ksi. The Navy method will better represent the actual yield strength if the stress relief treatment is omitted.

5) There is anistropy between longitudinal and transverse directions. The longitudinal direction is much stronger than the circumferential direction (170 Ksi vs. 150 Ksi yield strength).

6) Hardness values are not a valid evaluation as an acceptance criteria.

7) Full ring test may provide a good estimate of the actual case yield strength but considerable developments are required in the test methods.

8) The yield strength of three cases obtained by N.P.S. is lower than the cases cut up by N.W.S. (Seal Beach). The reason for this is unknown.

TABLES

TABLE 1

X-RAY TEST DATA (Procedure1)

CONDITION	A-4 CIRCULAR HPW (Cm)	A-4 STRAIGHTENED HPW (Cm)
As is	1.1	1.1
E.Polish.	.825	.825
EP+610F(1h.)	.72	.71
EP+610F+EP	.71	.70

TABLE 2

X-RAY TEST DATA (Procedure2)

A-13CIRCULAR HALF RING

CONDITION	HPW (Cm)
As is	1.05
1620F+Q+710F	.75
1620+Q+710F+EP	.70

TABLE 3

X-RAY TEST DATA (Procedure3)

A-8 CIRCULAR HALF RING

CONDITION	HPW (Cm)
As is	1.08
1.roll(8 passes)	1.08
2.roll(7 passes)	1.10
3.roll(7 passes)	1.10

TABLE 4

X-RAY TEST DATA (Procedure 3)

CONDITION	HPW (Cm)
As is	1.08
1.rolled	1.08
1.roll+EP	.84
1.roll+EP+610F+EP	.835

TABLE 5

X-RAY TEST DATA (Procedure3)

CONDITION	HPW (Cm)
As is	1.08
2.rolled	1.1
2.roll+EP	.83
2.roll+EP+610F+EP	.79

TABLE 6

X-RAY TEST DATA (Procedure3)

CONDITION	HPW (Cm)
As is	1.08
3.roll	1.10
3.roll+EP	.83
3.roll+EP+610F+EP	.75

TABLE 7

X-RAY TEST DATA (Procedure3)

CONDITION	HPW (Cm)	Thickness
As is	1.08	.076"
1roll+EP+610F+EP	.835	.075"
2,roll+EP+610F+EP	.790	.0749
3.roll+EP+619F+EP	.75	.0748

TABLE 8

CIRCUMFERENTIAL (e,f,g,h) RING+CUT+STRAIGHTENED
MACHINED+610F S.R. (30min.)
(N.P.S. Specimens Figure 4)

TENSILE TEST DATA

SPECIMEN	AREA	UTS (Ksi)	YS (Ksi)	HARDNESS (C)
e1	.02128	157.42	149.20	45.0
e2	.01760	167.61	155.97	45.3
e3	.01950	161.54	151.23	46.0
f1	.02130	160.80	149.30	46.2
f2	.02176	166.60	153.95	42.2
f3	.02110	161.14	151.18	45.3
g1	.02120	162.74	152.12	41.3
g2	.01743	163.22	150.60	40.7
g3	.01550	158.71	150.00	39.9
h1	.01800	162.78	150.00	39.6
h2	.01730	164.74	148.84	39.6
h3	.01940	158.50	145.88	39.5

AVG UTS : 162.15 q=3.01
AVG YS : 150.69 q=2.46 q=standard deviation
AVG HARD.: 43.2 q=3.78

TABLE 9

LONGITUDUNAL(c,d) SPECIMENS+NO STRAIGHT.+NO S.RELIEF

(N.P.S. Specimens Figure 4)

TENSILE TEST DATA

SPECIMEN	AREA	UTS(Ksi)	YS(Ksi)	HARDNESS
c1	.01293	175.95	168.21	37.6
c2	.01310	198.47	188.17	38.4
c3	.01450	177.93	172.4	37.2
c1-1	.01414	174.14	169.02	37.0
c1-2	.01420	185.91	172.53	39.5
c1-3	.01380	180.07	169.20	37.8
d1	.01471	178.45	166.55	39.0
d2	.01510	182.78	169.54	38.7
d3	.01344	178.94	169.64	39.5
d1-1	.01440	177.43	164.93	38.3
d1-2	.01635	168.50	156.57	38.6
d1-3	.01425	182.45	168.42	39.8

AVG UTS : 180.09Ksi q=7

AVG YS : 169.60Ksi q=6.8

AVG HARD.: 38.5 q=.88

TABLE 10

FULL RING SPECIMENS(N.P.S. Specimens Figure 4)

TENSILE TEST DATA

SPECIMEN	AREA	UTS (ksi)	YS (ksi) *
a1	.04064	144.93	143.95
a2	.04976	158.00	134.94
a3-1	.01984	163.56	148.69
a3-2	.02067	155.26	143.18
b1-1	.01900	160.35	148.52
b1-2	.01785	163.34	154.93
b2	.03792	154.40	152.95
b3	.03780	152.91	151.06

* The non-linearity of the load-deflection curve for these tests makes the reported yield strength very questionable.

TABLE 11

STRAIGHTENED+610F S.RELIEF (30min.)

(N.W.S. Specimens,Figure 3).

TENSILE TEST DATA

SPECIMEN	AREA	UTS(Ksi)	YS(Ksi)	HARDNESS
A13	.01860	189.25	173.39	41.0
A29	.01941	176.42	160.97	41.0
A28	.01977	177.06	160.87	40.0
A4	.02130	172.77	157.28	40.5
A3	.01910	184.82	170.16	40.0
A10	.01786	197.65	181.97	40.5
A7	.01840	172.28	161.68	39.5
A6	.01970	181.72	166.50	41.0
A12	.01910	186.38	171.73	40.0
A25	.01950	192.30	174.36	41.0
A8	.01900	186.84	171.05	41.0
A23	.01932	180.12	164.60	40.0
A2	.01840	171.20	160.87	40.0
A27	.01930	182.12	167.88	40.5
A17	.01800	184.72	159.72	40.0
B29	.01719	170.08	157.00	38.0
B10	.01685	178.04	162.61	37.5
B12	.01645	178.72	164.13	37.5
B20	.01656	180.86	165.46	37.5
B9	.01686	183.87	169.04	38.0
B16	.01618	177.69	162.23	38.0
B28	.01810	173.48	157.73	38.0
C14	.01622	175.66	162.72	38.0
C11	.01594	183.34	167.67	38.0
C28	.01652	181.59	165.25	38.0
C27	.01615	179.56	164.08	38.0
C19	.01627	169.29	156.08	37.5
C23	.01631	175.35	162.48	37.5

TABLE 11 Continued

SPECIMEN	AREA	UTS (Ksi)	YS (Ksi)	HARDNESS
C20	.01688	175.64	162.61	38.0
C25	.01619	180.67	169.55	38.0
C4	.01585	180.13	165.62	38.0
C12	.01585	176.66	160.88	37.0
C3	.01620	175.31	160.50	38.5
G2	.01584	174.24	161.62	38.5
G19	.01562	165.81	153.01	37.0
G26	.01590	171.38	159.75	38.0
K2	.01525	175.41	162.62	37.5
K1	.01530	173.20	160.13	37.5
J16	.01369	115.04	109.57	23.5
D9	.01884	84.92	80.94	22.0
E5	.01373	107.06	104.15	20.0

SPECIMENS	AVG UTS	Q	AVG YS	Q	AVG HARD.
A	182.71	6	162.78	5	40.0
B	177.53	4	162.60	4	38.0
C	177.56	4	163.40	3	38.0
G	170.48	3	158.12	4	37.5
K	174.3	1	161.38	1	37.0
A+B+C	178.58		163.59	(First 6"of case)	

TABLE 12

CIRCULAR+STRAIGHTENED+1620F+QUENCH+710F S.R.(30min.)

(N.W.S. Specimens,Figure 3).

HEAT TREATED SPECIMENS TENSILE TEST DATA

SPECIMEN	AREA	UTS(Ksi)	YS(Ksi)	HARDNESS
A25	.02067	140.78	131.35	41.0
A29	.02030	137.93	130.79	40.5
A30	.02045	171.15	157.70	41.0
A15	.02104	154.47	140.68	42.0
A6	.02064	160.61	145.35	42.0
A12	.01994	155.71	140.42	41.0
A23	.01718	161.23	150.47	41.0
B29	.01340	152.61	144.02	40.0
B9	.01630	153.68	149.08	40.5
B10	.01620	168.83	156.79	40.5
C26	.01757	151.39	143.71	42.0
C4	.01747	145.39	131.65	40.5
C28	.01580	160.75	124.68	41.0
K10	.01510	153.97	148.34	41.0
K2	.01440	163.19	155.55	40.5
K1	.01499	160.10	150.10	41.0
J16	.01210	159.10	151.24	41.0
D9	.01354	166.17	155.10	40.0

AVG UTS(Ksi)	q	AVG YS(Ksi)	q	AVG HARD.
156.50	8.7	144.83	9.5	40.5

TABLE 13

CIRCULAR+STRAIGHTENED+NO S.RELIEF

(N.W.S. Specimens,Figure 3).

TENSILE TEST DATA

SPECIMEN	AREA	UTS(Ksi)	YS(Ksi)	HARDNESS
A23	.01986	184.29	159.12	42.0
A27	.02060	186.40	-------	44.0
B28	.01750	173.71	157.14	40.5
B12	.01680	171.13	160.71	40.5

SPECIMENS	AVG UTS(Ksi)	AVG YS(Ksi)	AVG HARD.
A	185.34	159.12	43.0
B	172.42	158.93	40.5

TABLE 14

CIRCULAR+STRAIGHTENED+800F S.R.(30min.)

(N.W.S. Specimens,Figure 3).

TENSILE TEST DATA

SPECIMEN	AREA	UTS(Ksi)	YS(Ksi)	HARDNESS
A17	.01897	150.24	139.70	37.0
C11	.01640	151.83	144.82	37.5

TABLE 15

CIRCULAR+STRAIGHTENED+400F S.R.(30min.)

(N.W.S. Specimens,Figure 3).

TENSILE TEST DATA

SPECIMEN	AREA	UTS(Ksi)	YS(Ksi)	HARDNESS
A21	.01812	184.33	168.32	40.0
C20	.01721	177.22	163.57	40.0

TABLE 16

1/2 CIRCULAR+STRAIGHTENING+NO STRESS RELIEF

TENSILE TEST DATA (N.P.S.)

SPECIMEN	AREA	UTS(Ksi)	YS(Ksi)	HARDNESS
1-1	.01763	162.22	133.86	34.5
1-2	.01633	165.34	131.66	32.5
2-1	.01674	165.17	------	35.0
2-2	.01733	164.45	------	33.5
3-1	.01467	164.28	132.92	34.0
3-2	.015714	164.82	136.18	35.0

AVG UTS(Ksi)	q	AVG YS(Ksi)	q
164.38	1.7	133.65	1.6

OTHER 1/2 HALF RINGS+STRAIGH.+610F S.R.(30min.)

SPECIMEN	AREA	UTS(Ksi)	YS(Ksi)	HARDNESS
1-1	.01661	162.55	145.09	37.5
1-2	.01626	167.89	150.98	37.0
2-1	.16900	162.72	146.15	36.0
2-2	.01732	167.44	150.11	37.5
3-1	.01487	167.79	153.33	36.0
3-2	.01496	165.44	147.06	38.0

AVG UTS(Ksi)	q	AVG YS(Ksi)	q
165.64	2.3	148.79	2.9

TABLE 17

1/2 CIRCULAR+STRAIGHT.+650F (30min.) S.R.

TENSILE TEST DATA (N.P.S.)

SPECIMEN	AREA	UTS(Ksi)	YS(Ksi)	HARDNESS
1-3	.01577	159.80	148.07	40.0
1-4	.01480	162.16	147.64	41.0
2-3	.01661	164.36	150.51	41.0
2-4	.01720	162.80	149.88	42.0
3-3	.01622	162.30	147.97	39.0
3-4	.01396	151.08	139.62	41.0*

AVG UTS(Ksi)	q	AVG YS(Ksi)	q
162.28	1.4	147.28	3.5

OTHER 1/2 CIRCULAR+STRAIGHT.+700F S.R.(30min.)

SPECIMEN	AREA	UTS(KSI)	YS(KSI)	HARDNESS
1-3	.01515	158.41	146.53	38.0
1-4	.01429	152.55	142.05	37.0
2-3	.01688	162.62	148.10	32.0
2-4	.01765	158.60	148.68	31.0
3-3	.01577	162.97	151.55	35.0
3-4	.01430	154.20	144.05	34.0

AVG UTS(KSI)	q	AVG YS(KSI)	q
158.23	3.8	146.82	3.1

TABLE 18

TENSILE TEST DATA (N.P.S. Specimens)

Averages From Tables 8, 9, and 10.

CONDITION	AVG UTS(KSI)	AVG YS(KSI)
FULL RING+NO STRAIGH.+NO S.R.	156.60	147.28
LONGITUDUNAL+NO STRAIGH.NO S.R.	180.09	169.60
TRANSVERS+STRAIGH.+600F S.R.	162.15	150.69

TABLE 19

TENSILE TEST DATA

Averages From Tables 11, 12, 13, 14, and 15.

The Specimens Obtained From N.W.S.

CONDITION	LOCATION A UTS	A YS	B UTS	B YS	C UTS	C YS
STRAIGH.+NO S.R	185.34	159.13	172.42	158.93	------	------
STRAIGH+1620F+Q+710F	154.55	143.31	153.14	146.55	135.88	123.97
STRAIGH.+400F S.R.	184.33	168.32	------	------	177.22	163.57
STRAIGH.+610F S.R.	180.63	164.78	177.53	162.60	177.56	163.40
STRAIGH.+800F S.R.	150.24	139.70	------	------	151.83	144.82

TABLE 20

TENSILE TEST DATA (N.P.S. Specimens)

Averages From Tables 16, and 17.

CONDITION	AVG.UTS(KSI)	AVG.YS(KSI)
1/2CIRC.+STRAIGH.+NO S.R.	164.38	133.65
1/2CIRC.+STRAIGH.610F S.R.	165.64	148.79
1/2CIRC.+STRAIGH+650F S.R.	162.28	147.28
1/2CIRC.+STRAIGH+700F S.R.	158.23	146.82

FIGURES

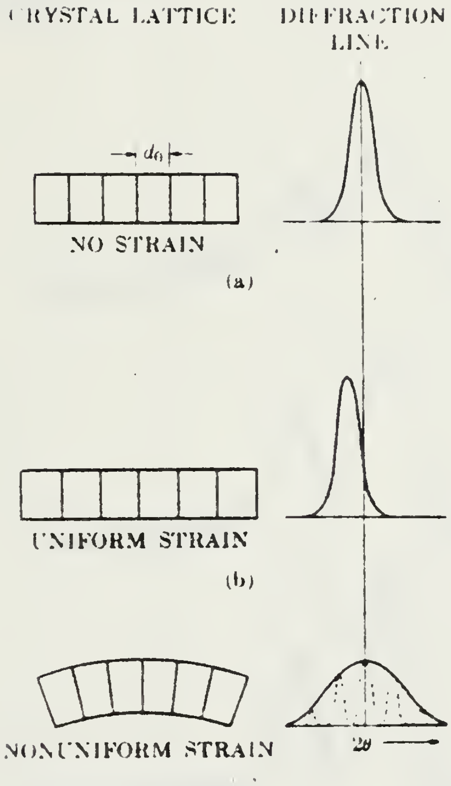


Figure 1. The Diffraction Lines According to the Different Involved Strains [Ref. 6]

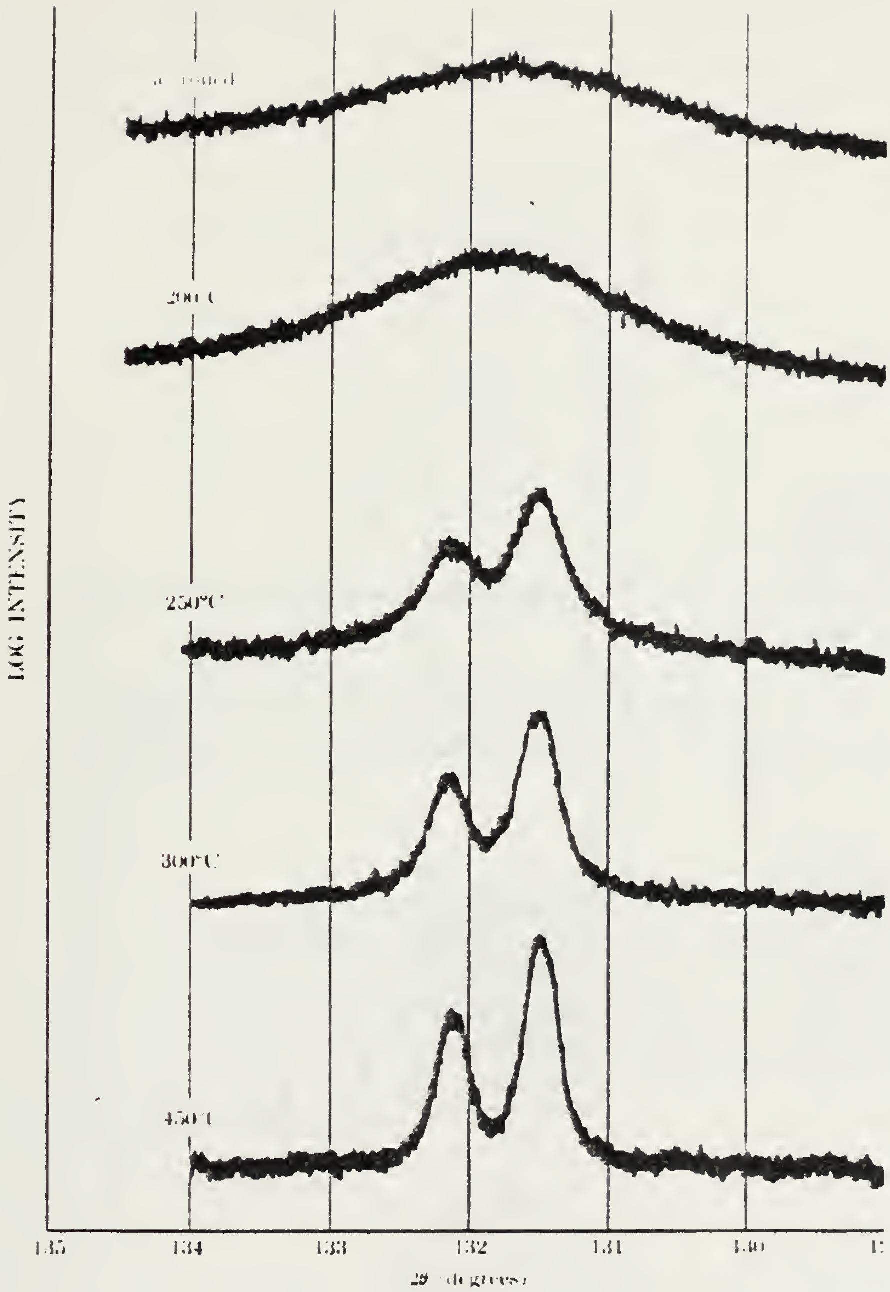


Figure 2. Broadening and Sharpening of Diffraction Lines Due to Cold Work and Annealing [Ref. 6]

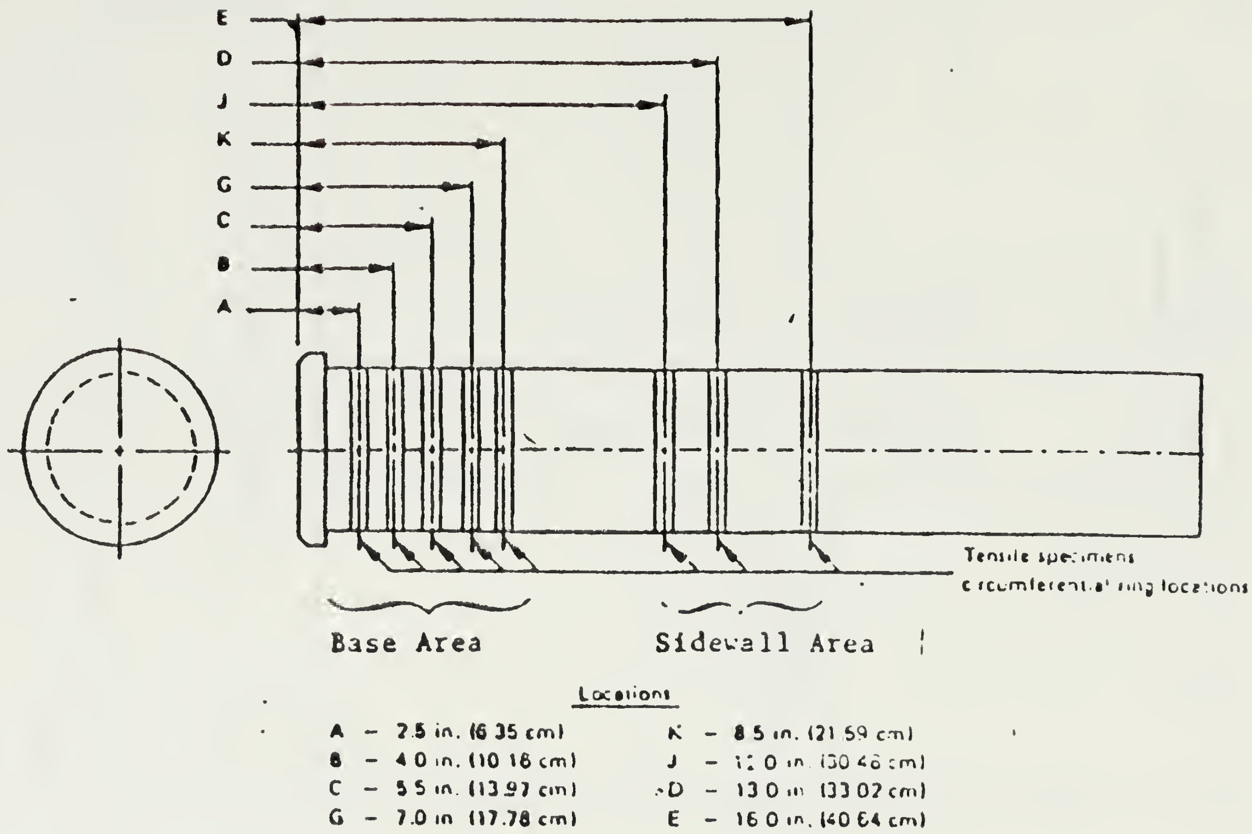


Figure 3. Location of N.W.S. Specimens [Ref. 1]

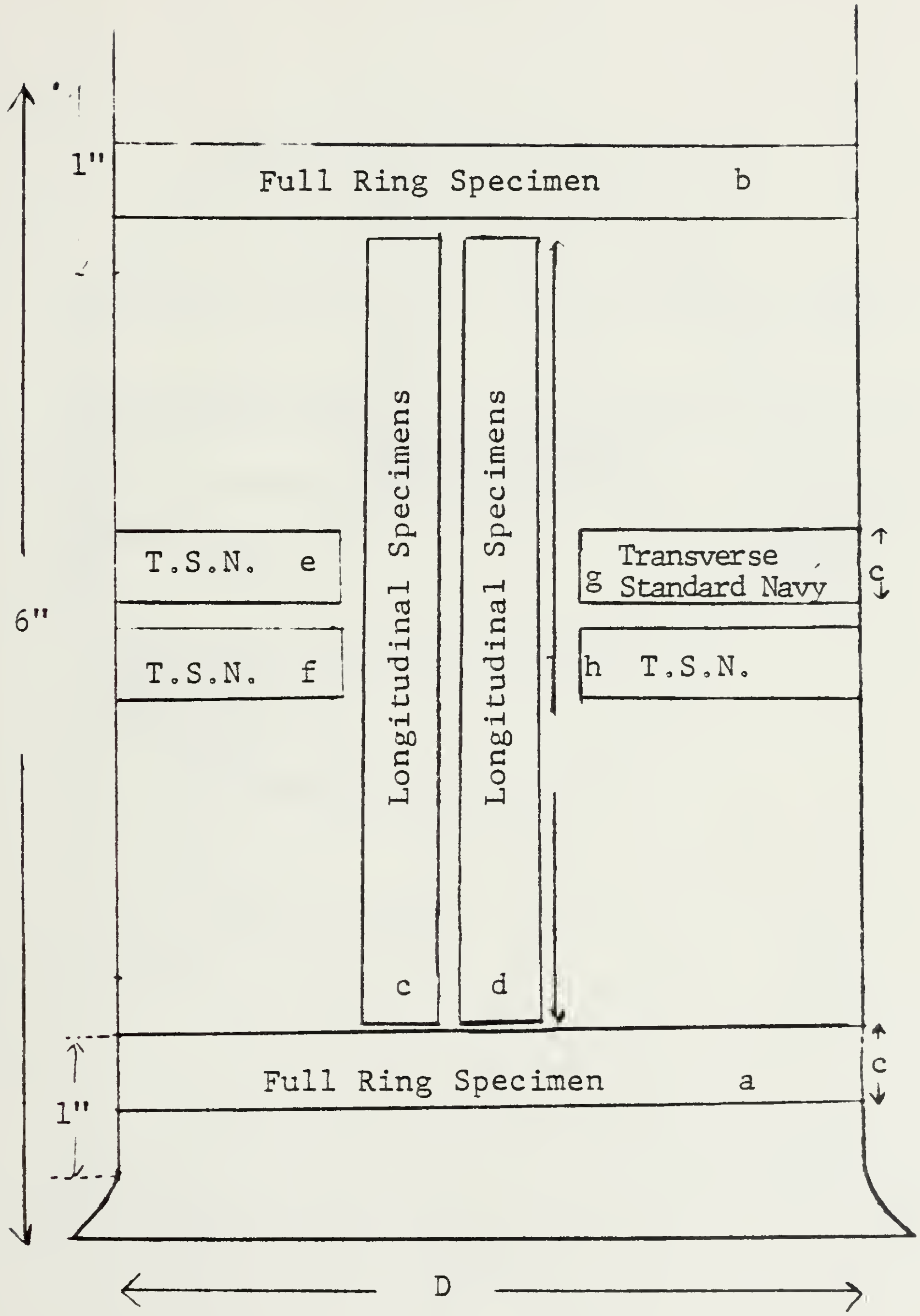
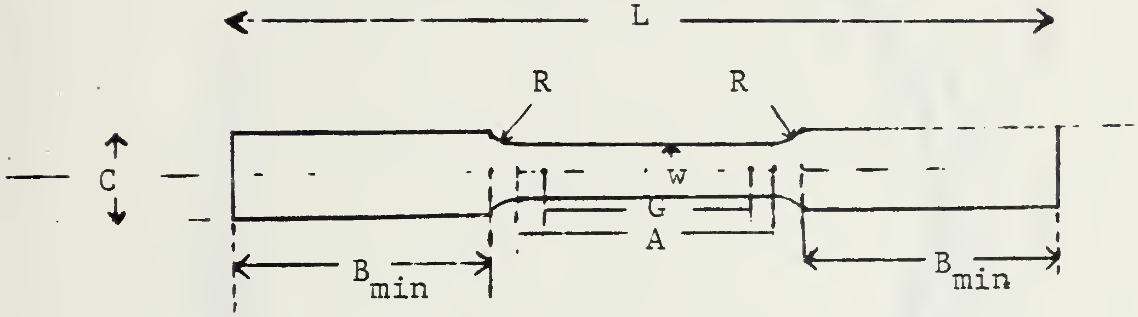


Figure 4. Locations of N.P.S. Specimens



B = 1 1/4"

A = 1 1/4"

G = 1" ± 0.003

R = 1/4"

C = 3/8"

W = 0.250" ± 0.002

L = 4"

Figure 5. ASTM E8 Tensile Test Specimen

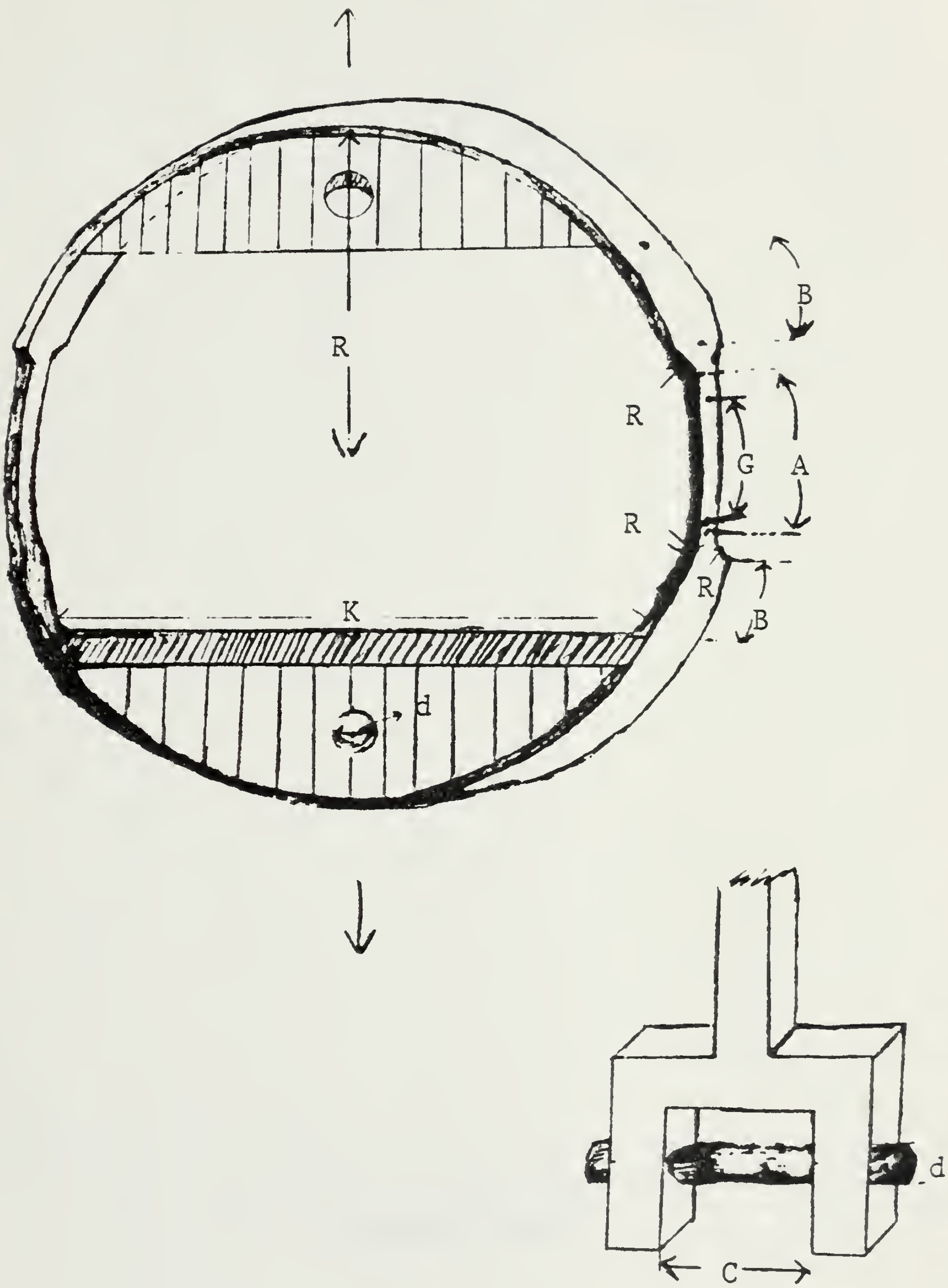


Figure 6. Full Ring Specimen Prepared at N.P.S.

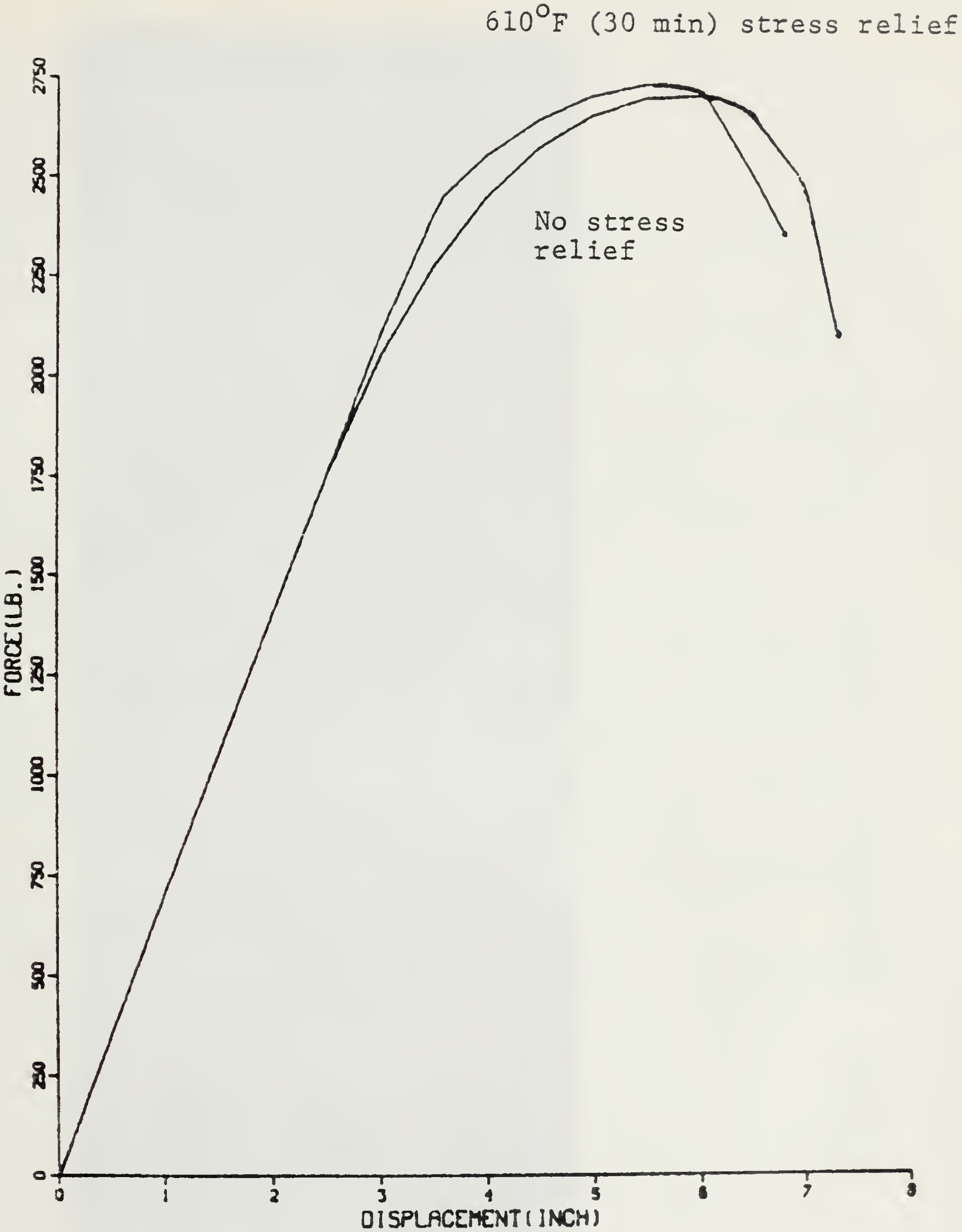


Figure 7. Tensile Test Curves Showing the Strain Aging Effect (From N.P.S. Specimens)

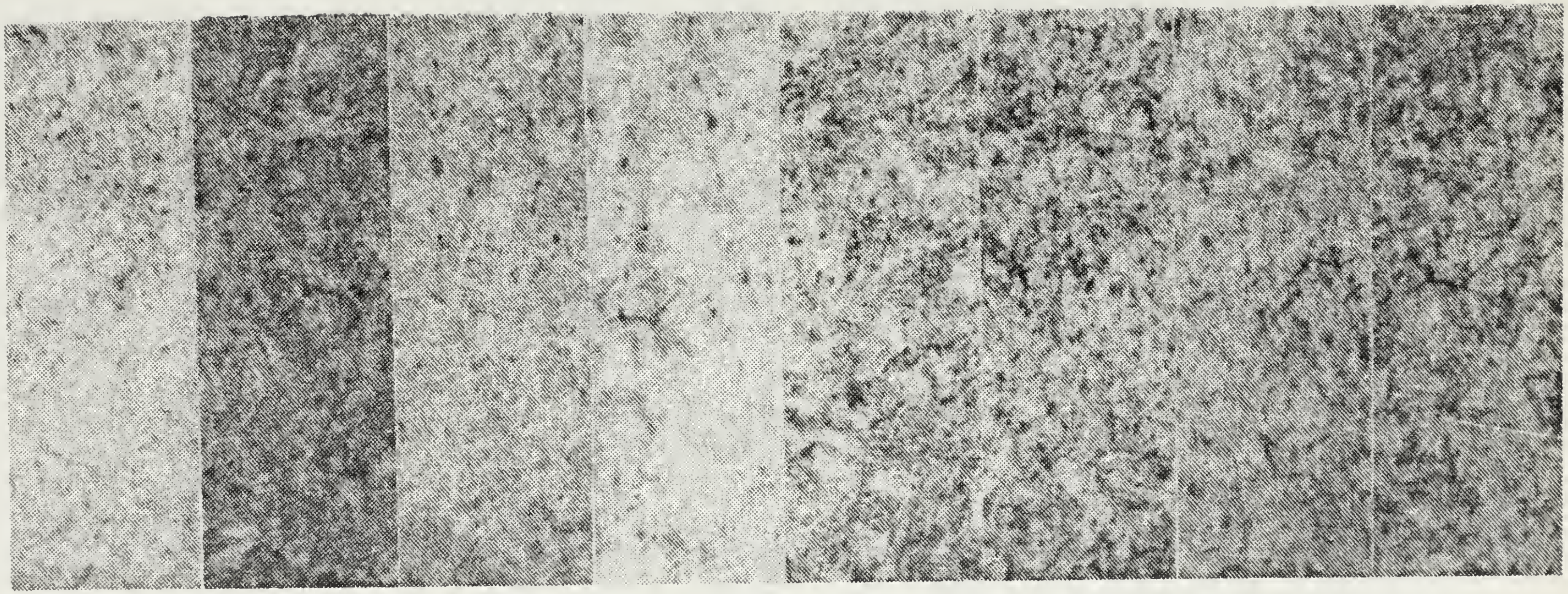


Figure 8. The Structure Change of the Case from the Base to the Mouth

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